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Which traits drive consumer preferences for gene-edited foods in Spain

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Abstract

This study examines consumer preferences for the potential benefits of CRISPR technology using a best–worst scaling (BWS) approach within an online survey of a representative Spanish sample. The BWS discrete choice experiment focuses on seven key environmental and health-related benefits of CRISPR, using tomatoes as a case study. The selected benefits are derived from science-based information and align with the EU regulatory context, following the European Commission's 2023 proposal on gene-editing technologies. Estimates from a random parameter logit (RPL) model indicate that pesticide reduction is the most highly valued benefit, followed by water saving and health improvement, thereby highlighting the combined influence of environmental and personal benefits on consumer acceptance of genetically engineered food. The significant standard deviations in the RPL estimates reveal substantial heterogeneity in preferences, which is further examined by identifying two distinct consumer segments. While both segments strongly prioritise pesticide reduction, one is primarily motivated by environmental sustainability outcomes, whereas the other places greater emphasis on health and sensory quality improvements. These findings underscore the need for targeted communication strategies to address distinct consumer concerns, rather than a uniform approach.

Keywords: Consumer behaviour, Gene editing, CRISPR, Best–worst, Willingness to pay, Spain

Introduction

In a world where challenges such as climate change, environmental degradation and the depletion of natural resources are becoming increasingly acute, ensuring global food security while preserving agricultural sustainability has become increasingly urgent. To ensure not only sufficient production but also the availability of affordable, nutritious and healthy food, advanced plant breeding technologies, particularly gene editing (GE), have emerged as promising tools to support sustainable intensification of agriculture (Campbell et al. 2017). Among these technologies, Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) has gained particular attention due to its precision, efficiency, and flexibility in modifying specific DNA sequences without introducing foreign genes (Hu et al. 2022). Unlike genetically modified organisms (GMOs), CRISPR-based GE can produce transgene-free varieties that are, at the molecular level, indistinguishable from those created through conventional breeding. This distinction makes CRISPR a particularly promising solution for addressing public concerns surrounding GMOs, especially in regions with historically low acceptance such as the European Union (EU) (Frewer et al. 2013; Macilwain 2015).

In agriculture, GE and particularly CRISPR applications are already demonstrating notable agronomic and nutritional benefits (Karavolias et al. 2021). These include the development of crops with enhanced disease resistance (Schneider et al. 2023), rice varieties bred for improved yield (Rengasamy et al. 2024), and wheat with optimised nutritional profiles, such as low-gluten coeliac-safe traits (Sanchez et al. 2023) and hypoimmunogenic gluten varieties (Jouanin et al. 2018). These traits align closely with broader policy objectives of reducing agrochemical inputs and increasing climate resilience (Pretty 2018; Kumar et al. 2020). However, despite its technical advantages, the adoption of GE crops within the EU must follow the same regulatory process as GMOs. Since the 2018 ruling by the Court of Justice of the European Union, GE techniques are considered GMOs (Court of Justice of the European Union (CJEU), 2018) and face lengthy and costly regulatory procedures compared with the USA, Canada and many other countries (Eriksson et al. 2020). This has prompted growing calls from both the scientific and policy communities for a more proportionate, evidence-based regulatory approach (Smyth 2022; Wesseler et al. 2023).

In response, the European Commission (EC) proposed in July 2023 a new regulatory framework differentiating between two categories of new genomic techniques (NGTs) for regulatory purposes: Category-1 GE crops, which could also occur naturally or through conventional breeding and would therefore face a streamlined approval process; and Category-2 GE crops, which remain subject to existing GMO legislation (European Commission (EC) 2023). The Commission's proposal includes several provisions: mandatory public listing of Category-1 plants, a ban on their use in organic agriculture and restrictions on patentability (European Parliament 2024a, b). The co-legislators adopted their negotiating positions on 24 April 2024 (European Parliament)([1]) and 14 March 2025 (European Council) ([2]), and trilogue negotiations for the adoption of the final regulation are currently ongoing. Regardless of legal authorisation, the long-term success of GE crops in European markets will ultimately depend on consumer acceptance and willingness to pay (WTP).

Since the first valuation study of GE foods in 2018 (Shew et al. 2018), academic interest in consumer behaviour has expanded considerably. By late 2024, more than fifty peer-reviewed studies had been published, including over a dozen focusing specifically on consumer preferences for GE crops and their implications for agriculture (Lemarié and Marette 2022; Nguyen et al. 2023; Caputo et al. 2025a). A consistent finding across this body of work is that European consumers remain poorly informed about GE technologies, with confusion between GE and GMOs still widespread (Caputo et al. 2022; Götz et al. 2022; European Food Safety Authority 2022; Deng et al. 2024). In Spain, this knowledge gap is similarly pronounced (Ballco et al. 2025). Despite limited information, European consumers generally view GE foods more favourably than GMOs (Bearth et al.

[1] https://www.europarl.europa.eu/doceo/document/TA-9-2024-0325_EN.html

[2] https://data.consilium.europa.eu/doc/document/ST-6426-2025-INIT/en/pdf

2022, 2024; Atimango et al. 2024; Deng et al. 2024). However, high levels of food technology neophobia persist (Beghin and Gustafson 2021; Götz et al. 2022; Ortega et al. 2022), and many consumers require price discounts to consider purchasing GE products (Yang and Hobbs 2020; Muringai et al. 2020; Marette et al. 2021a, b; McFadden et al. 2021; Ufer et al. 2022; Ortega et al. 2022; Martin-Collado et al. 2022; Hao et al. 2024). These findings are based on consumers not being provided with information about the benefits that GE varieties may offer (Ballco et al. 2025; Caputo et al. 2025a). However, studies show that providing clear and targeted information, particularly concerning environmental and health benefits, can significantly increase acceptance and WTP (Kilders and Caputo 2021; Caputo et al. 2022, 2025a; Götz et al. 2022; Hu et al. 2022; Baum et al. 2023; Deng et al. 2024; Kilders and Ali 2024). When these benefits are made explicit, the price discounts required by consumers to choose GE products, especially those based on CRISPR over conventional ones fall significantly and may, in some cases, reach zero or even become price premiums (Hu et al. 2022; Deng et al. 2024; Ballco et al. 2025). While these studies provide valuable insights into consumer valuation of GE foods, their focus has largely centred on monetary attributes and WTP estimates. The present study advances the field in two important respects. First, it provides a structured hierarchy of perceived benefits using Best–Worst Scaling (BWS), enabling a more nuanced understanding of how consumers prioritise regulatory-relevant benefits. Second, it incorporates explicit behavioural segmentation, identifying distinct preference profiles and offering deeper insight into consumer heterogeneity. These contributions enhance the interpretive and strategic value of the findings beyond price-based metrics and merit further emphasis.

In this context, the objective of the present study is to explore which potential benefits of CRISPR technology are most and least appealing to consumers using a BWS approach. BWS is a discrete choice modelling technique that excels in eliciting preferences and estimating the relative importance of different features (Marley and Louviere 2005). It identifies which perceived benefits consumers value most and least in choice-based scenarios, offering a more nuanced understanding of decision-making processes. The study focuses on seven key environmental and health benefits associated with CRISPR technology and uses tomatoes as a case study. In our application, we provide consumers with science-based information on various plant breeding methods and the differences among them, adopting a neutral tone. The selection of benefits reflects the EU's regulatory landscape following the Commission's 2023 proposal.

To the best of our knowledge, this is the first study to apply BWS to CRISPR-edited food in Spain and the first to explore consumer valuation of GE food products in the EU following the EC's 2023 regulatory developments. While Ballco et al. (2025) analysed Spanish consumers' acceptability and WTP for CRISPR-edited tomatoes using a discrete choice experiment, their study focused primarily on monetary trade-offs and purchase behaviour. Given that perceived risk is strongly influenced by regulatory cues (Bearth and Siegrist 2016), and that public institutions and scientific organisations remain among the most trusted sources of food-related information in Europe (European Food Safety Authority 2022), this research offers timely and policy-relevant insights into consumer perceptions regarding the type of benefits that could justify simplified approval procedures. The findings therefore aim to support policymakers, plant breeders, and food-system actors in developing effective communication strategies and market policies aligned with consumer values and expectations.

Materials and methods

The methodology of this research involves a BWS experiment, designed to determine which potential benefits of CRISPR-editing technology are most and least appealing to consumers. BWS is particularly effective for ranking a range of items, as it simplifies the decisions-making process. Instead of ranking the entire set of items at once, respondents are presented with a series of smaller tasks, each containing a subset of items. Following Finn and Louviere (1992), for each task they are asked to choose the most (best) and least (worst) desirable item. This approach is based on the premise that people are better at evaluating extremes than at providing full-rankings (Louviere 1993), and helps to eliminate scale-use bias, as only the extremes are considered (Baumgartner and Steenkamp 2001).

Data collection and survey description

The BWS experiment uses tomatoes as the study product and was part of an online survey. The survey was administered by a professional market research firm with over two decades of experience. Since 2005, the company has maintained a certified consumer panel representative of the population, in compliance with ISO 20252 standards (International Organization for Standardization). Data collection took place in Aragón, located in north-eastern Spain, during April 2024. This region was selected for its high degree of representativeness of the Spanish population, given that its socio-demographic profile closely aligns with that of the Spanish Census of Population. The target population comprised individuals aged 18 and above who are primarily responsible for food shopping within their households. The sample was stratified by gender and age.

A pilot survey involving 60 respondents was conducted to evaluate the clarity of the questionnaire items and to estimate the time required for completion prior to distributing the final version. The final questionnaire was structured into several sections. The first section included a screening question regarding responsibility for food shopping to exclude individuals who never engage in grocery shopping. The second section asked participants to self-assess their subjective knowledge of plant breeding techniques (PBT). The third section explored tomato purchasing and consumption habits. In the fourth section, after being provided with information on PBT and relevant EU regulations (see Appendix I), participants completed the BWS experiment. The fifth section assessed participants' willingness to consume CRISPR-edited tomatoes, their perceptions of the potential risks associated with CRISPR, and their trust in institutions linked to CRISPR technology. The final section collected background information, including socio-demographic characteristics (such as gender, age, household size, income, and education level), as well as indicators of food technology neophobia and concerns related to the social and environmental impacts of food production. Since this study formed part of a broader research project, the questionnaire also contained additional sections not addressed in this paper.

A four-point scale (none, low, medium or high) was used to measure subjective knowledge of various breeding techniques, such as traditional, cisgenic, CRISPR, and transgenic (GMO). Both cisgenic and CRISPR are considered GE technologies that fall under the NGT regulation. Participants' willingness to consume CRISPR-edited tomatoes was measured on a five-point scale ranging from 1 (not willing at all) to 5 (very willing). For subsequent analyses, values of 4 and 5 were grouped and classified as medium-to-high willingness. Perceptions of the potential risks of CRISPR were assessed by eliciting agreement with six items measured on a five-point Likert scale (1 = totally disagree to 5 = totally agree), adapted from Baum et al. (2023) and Farid et al. (2020) (see Table 8 in Appendix II). For further analyses, responses on this scale were grouped into three categories: disagreement (scores of 1 and 2), indifference (scores of 3), and agreement (scores of 4 and 5).

Trust in CRISPR-related institutions was measured using a five-point Likert scale, differentiating between developers or scientists in public and private institutions; users or farmers; regulators; and information sources (either traditional media or social networks; two items), following the approaches of Farid et al. (2020) and Uddin et al. (2022) (see Table 9 in Appendix II). A composite trust score was calculated for each of the four groups: ranging from 2 to 10 for information sources (each based on two items), and from 1 to 5 for public, private developers, farmers and regulators (each based on a single item). Likewise, a general trust scale was calculated across all six institutions.

Food technology neophobia was assessed using an abbreviated scale on a five-point Likert scale, following Borrello et al. (2021) (see Table 10 in Appendix II). A cumulative score was calculated by summing the responses across the nine items, resulting in a single score ranging from 9 to 45.

Finally, social and environmental concerns related to food production and consumption were measured using 14 items, each evaluated on a five-point scale (1 = only slightly concerned to 5 = extremely concerned), as used by Borrello et al. (2021) (see Table 11 in Appendix II). As with previous scales, a cumulative score was calculated, ranging from 14 to 70.

Best–worst scaling design

This method was developed by Finn and Louviere (1992) and has since been widely applied to analyse consumer preferences for food attributes and policies (Török et al. 2023; Schuster et al. 2024; Caputo et al. 2025b).

The benefits evaluated in this study were selected based on the sustainability-related traits outlined in Article 22 of the proposed Regulation of the European Parliament and of the Council on plants obtained by certain new genomic techniques and their food and feed, which also amends Regulation (EU) 2017/625 (listed in part 1 of Annex III). These traits were associated with their implicit benefits as shown in Table 12 in Appendix III. Some trait descriptions were slightly rephrased to improve clarity for respondents. Table 1 presents the seven benefits along with the associated traits as shown to respondents.

Considering the seven characteristics (items = 7) and a question format involving cards with three items each (size = 3), a full factorial design would require 35 tasks.[3] To reduce

[3] $Tasks = \frac{Items \times (Items-1) \times \cdots \times (Items-Size+1)}{Size!}$

Table 1 Description of items in the Best–Worst experiment

Item (*k*)	Description	Abbreviation
1	Increase their resistance to diseases and pests, leading to a reduction in the use of pesticides in food production	Pesticide
2	Delay the ageing of products (extending shelf life, preventing fruit browning, etc.), thus reducing food waste	Food waste
3	Improve the sensory characteristics of products (taste, colour, texture, seedlessness, etc.)	Sensory
4	Increase resistance to drought, temperature, salinity, etc., which leads to stabilising or increasing production yields	Yields
5	Make more efficient use of soil nutrients, thus reducing the use of fertilisers	Fertilizer
6	Make more efficient use of water, leading to reduced water consumption	Water
7	Improve the nutritional and health characteristics of food, either by increasing beneficial nutrients (fibre, vitamins, antioxidants, etc.) or by reducing potentially harmful substances (toxins, allergens, gluten, etc.)	Health

[a] It is worth noting that respondents who reported seldom purchasing food represent less than 1% of the sample, and therefore their inclusion does not materially affect the overall findings. We believe this approach enhances the inclusivity and relevance of the study without compromising its validity

Table 2 Example of Best–Worst task

Most important	Task 1	Least Important
☐	Reduce food waste	☐
☐	Reduce water consumption	☐
☐	Stabilize or increase production yields	☐

the number of tasks presented to respondents, we use a Balanced Incomplete Block Design (BIBD) following Louviere et al. (2010). The BIBD reduces this to seven tasks, which is the minimum number of cards that satisfies the following properties: each task contains the same number of items; each item appears the same number of times across all tasks; and each item is paired equally often with every other item. In each task, participants were asked to select the characteristic they considered most important and least important (Loureiro and Dominguez Arcos 2012).

The BW questions were framed as follows (see an example of the tasks in Table 2:

> *"Imagine you are buying fresh tomatoes to eat at home, and some of their traits have been genetically edited using CRISPR to achieve one of the following goals (see Table1). These benefits are presented in groups of three in the following questions. Please indicate which you consider to be the most important, and which the least important."*

The BWS data were analysed in two stages. First, descriptive scores were calculated. Second, an econometric estimation was conducted within a random utility framework (McFadden 1973).

BWS data analysis: descriptive scores

Let B_{kn} represent the number of times respondent n chooses item k as the best alternative, and W_{kn} the number of times respondent n choses item k as the worst alternative. Each item appears three times across the seven tasks. Accordingly, both B_{kn} and W_{kn} range from 0 and 3. Aggregating across respondents yields the count scores B_k and W_k, which represents the total number of times item k is selected as best and worst, respectively, within the sample. Thus, B_k and W_k can range from 0 and 3 N, where N is the total number of respondents. A difference score is then calculated as the mean (across all individuals) of the difference between B_{kn} and W_{kn}. This score can be positive or negative, indicating whether an item is generally preferred or disliked. To facilitate interpretation, a ratio score is calculated as the square root of the ratio between B_k and W_k. This ratio score is then normalised relative to the highest value, resulting in a more intuitive indicator in which a value of 1 corresponds to the item with the highest relative preference (Loose and Lockshin, 2013).

BWS data analysis: Econometric analysis

In a second stage, consumer preferences for the potential benefits of CRISPR-edited tomatoes were analysed using a discrete choice model. According to the random-utility framework (McFadden 1973), the utility that individual n obtains from choosing alternative j in choice task s is defined as:

$$U_{\mathrm{njs}} = V_{\mathrm{njs}} + \varepsilon_{\mathrm{njs}} \tag{1}$$

where V_{njs} is the systematic (observed) component of utility, and ε_{njs} is the stochastic (unobserved) random component of utility. The observed component may be a function of characteristics (X_{njs}) such as *Pesticide*, *Food waste*, *Sensory*, *Yield*, *Fertilizer*, *Water*, and *Health* and individual-specific characteristics (Z_n). In the BWS framework, the respondent chooses the pair of characteristics (*i, j*) that maximises the difference in utility between the best and worst alternatives. Thus, the probability that respondent n chooses attribute i as best and j as worst in choice task s is the probability that the difference in utility between U_{nis} and U_{njs} is greater than all M other possible utility differences in that task s (Erdem et al. 2012). As differences in utility are modelled rather than absolute utilities, this approach is also known as a Maximum Difference Model (*MaxDiff*). Assuming that the error terms ε_{njs} are independently and identically distributed (i.i.d.), this probability takes the standard logit form:

$$\Pr\left(\mathrm{best} = i, \mathrm{worst} = j\right) = \frac{\exp\left(V_{\mathrm{nis}} - V_{\mathrm{njs}}\right)}{\sum_{p,q|p\neq q} \exp\left(V_{\mathrm{nps}} - V_{\mathrm{nqs}}\right)} \tag{2}$$

Parameters are estimated by maximising the log-likelihood function derived from this probability (Lusk and Briggeman 2009). The log likelihood for the full sample is the sum of their logarithms:

$$\ell(\boldsymbol{\beta}) = \sum_{n=1}^{N} \sum_{s=1}^{S_n} log\Pr\left(\mathrm{best} = i_{ns}, \mathrm{worst} = j_{ns}\right), \tag{3}$$

where the probabilities are given by Eq. (2). Because each best–worst choice reveals preferences not only for the selected pair but also implicitly for the remaining items, each choice task is expanded to include all possible best–worst combinations.

Given the panel nature of the data (each respondent completes seven choice tasks), two alternative models were estimated: a Conditional Logit Model (CL) and a Random Parameter Logit (RPL). The RPL model allows for preference heterogeneity by assuming that parameters follow a normal distribution, capturing individual-level variation in preferences. Alternative models that account for heterogeneous preferences include Latent Class (LC) and Hierarchical Bayes (HB) logit models (Lagerkvist et al. 2012). While the LC model identifies clusters of respondents with similar preference patterns, the HB logit model, similar to the RPL, estimates individual-level coefficients and can incorporate both between- and within-respondent heterogeneity (Lagerkvist et al. 2012). HB models can also provide more accurate predictions, particularly in small samples (Mühlbacher et al. 2016). In this paper, we favour the RPL model, as it is less computationally intensive than the alternative models and facilitates convergence.

To explore heterogeneity further, individual-level coefficients for parameters identified as random were calculated following the simulation-based procedure developed by Revelt and Train (2000) and Train (2003), using 200 Halton draws and 15 burn-in elements.

The resulting individual-specific coefficients were then used to classify respondents into clusters with similar preference patterns. Clustering was performed using the *k-means* algorithm with Euclidean distances, and the optimal number of clusters was determined using the Calinski–Harabasz (CH) criterion. The CH pseudo-F index (Caliński and Harabasz 1974) measures within-cluster compactness and between-cluster separation, with higher values indicating better clustering. Each cluster was subsequently characterised according to several profiling variables, including socio-demographic characteristics, tomato purchasing and consumption habits, knowledge of PBTs (particularly CRISPR), willingness to consume CRISPR-edited tomatoes, perceptions of CRISPR-related risks, trust in CRISPR-related institutions, food technology neophobia, and social and environmental concerns regarding food production. Bivariate analyses were used to statistically examine the differences across clusters, employing Chi-square tests for categorical variables and Kruskal–Wallis tests for continuous variables. All econometric estimations, including CL and RPL models (using the *cmclogit* and *mixlogit* commands; Hole 2007), cluster analysis and profiling, were conducted using STATA version 18 (StataCorp LLC. 2023).

Results

Sample description

Responses were collected from 550 individuals[4] in Aragón, a region in north-east Spain that is considered broadly representative of the national population. Table 3 provides the socio-demographic description with comparisons to Spanish population data where available. The sample is representative of the population of Aragón and also closely reflects the Spanish population, as no significant differences were observed in gender

[4] This final sample size for a confidence level of 95.5% (k = 2) when estimating proportions for the more conservative scenario (p = q = 0.5) results in a sampling error of ± 4% following the procedure outlined in Cochran (1977).

Table 3 Description of the sample (N = 550 individuals). Source: Own elaboration

Variable	Indicator	% sample	% Aragón population [a]	% Spanish population [b]
Gender [b]	Male	47.1	49.4	49.0
	Female	52.9	50.6	51.0
Age [b]	18–34 years old	20.0	21.0	22.2
	35–44 years old	17.1	16.2	17.1
	45–54 years old	23.4	19.3	19.6
	≥ 55 years old	39.4	43.6	41.1
Education*	Up to compulsory school (primary, secondary)	20.9	32.6	36.3
	High school or equivalent	25.6	24.1	23.0
	University	53.4	43.3	40.7
Net household income (€/month) ***,c	≤ € 1500 per month	15.8 [20.0]	28.3	28.3
	€ 1501–3000 per month	33.8 [42.8]	43.6	43.6
	€ 3001–5000 per month	24.7 [31.3]	21.9	21.9
	> € 5000 per month	4.6 [5.8]	6.2	6.2
	n.a	21.1 [0.0]	-	–
Household size***	Average size (std. deviation)	2.7 (1.1)	2.4	2.5
Household composition	With children (< 18 years old)	28.7	25.7	–
	With retired persons (> 65 years)	20.7	–	–
	Only adults (18–65 years old)	52.5	–	–

***, ** and * indicate significant differences between the sample and the population according to the Chi-square test (t test in the case of household size) at the 1%, 5% and 10% significance level. [a] Population figures for gender and age in Aragón in 2023, from INE (2024a); [b] Sources for the population are: INE (2024a) for gender and age (year 2023); EUROSTAT (2023) for education (year 2022); INE (2024b) for income (year 2023); INE (2024c) for household size (year 2024). [c] When non-reported income values are considered, the population shows significant differences. Non-significant differences are found, however, when the non-reported values are spread equally across categories (percentages in brackets)

and age. However, it exhibits a moderate bias towards highly educated individuals, with 53% of respondents holding a university degree compared with 41% in the general population ($p < 0.10$). This bias is commonly observed in samples drawn from online panels.

Regarding income, approximately 20% of respondents chose not to disclose their income. The largest proportion (33.8%) reported earning between €1,500 and €3,000 per month, while the smallest group (4.6%) reported monthly incomes exceeding €5,000. When considering only those who reported their income (figures in brackets), the income distribution does not significantly differ from the general population. The average monthly income reported in the sample[5] is €2,737, which is close to the national average of €2,902 (INE 2023). The average household size in the sample is 2.7, slightly higher than the population average of 2.5 ($p < 0.01$), with 29% of participants living in households with children.

Table 4 presents data on participants' purchasing and consumption habits. Most respondents are primarily responsible for household food shopping, with 57% indicating they are always responsible and a further 35% indicating they take on this role very often. Additionally, 52% of respondents reported purchasing organic products at least once in the year prior to the survey.

[5] Using income data in the sample available for 11 intervals and multiplying the respective proportions by the mid-point value in the interval, we approximate an average monthly income.

Table 4 Consumers' food and tomato purchase and consumption habits. Source: Own elaboration

Variable	Indicator	% of respondents
Food purchases		
Respondent responsible for purchases	Always	57.3
	Often	34.7
	Sometimes	7.4
	Seldom[a]	0.6
Organic food purchases	Yes	52.2
Tomatoes purchasing and consumption		
Tomato purchasing frequency	At least once a week	63.1
	Once or twice a month	31.4
	Never	5.4
Tomato purchasing seasons	Spring	16.0
	Summer	30.4
	Autumn	7.6
	Winter	6.7
	All seasons	63.4
Tomato consumption	Below average	21.1
	Average	39.1
	Above average	39.8
The price paid for tomatoes (€/kg)	Mean	2.55
	Median	2.32
	Percentile 75	3.00
Purchase of organic tomatoes	Organic	23.1
	Organic & conventional	20.4
	Organic only	1.6

Regarding tomato purchasing habits, 63% of respondents buy tomatoes at least once per week, and an equal proportion report purchasing tomatoes throughout the entire year. Compared to the national average consumption of fresh tomatoes (200 g per week; MAPA, 2024), 40% of the sample consume more than the average, while 39% consume around the average. The average price paid for tomatoes is €2.60 per kilogram, with a median price of €2.30 per kilogram; 75% of respondents report paying €3.00 or less per kilogram. These reported prices are consistent with local market prices for tomatoes in 2025, which range from €1.50 to €6.00 per kilogram with an average price of €3. In relation to organic tomatoes, 23% of respondents purchase them, although fewer than 2% purchase them exclusively.

Best–worst aggregate scores results

The descriptive results of the best–worst data are presented in Table 5.

The ranking based on the scaled ratio scores shows that *Pesticide* reduction is considered the most important attribute, with a significant gap compared to the second and third most valued attributes, namely *Water* saving and *Health* improvement. The standard deviations show that variability across consumers regarding the importance of *Pesticide*, *Fertilizer*, *Water* and *Health* is similar (standard deviation around 1.5). In contrast, variability is greater for the *Sensory* and *Food waste* attributes (standard deviations

Table 5 Description of best–worst data ($N=550$)

Item (k)	B^k	W^k	BW^k	Mean (BW_n^k)	Std (BW_n^k)	$RatioScore:\sqrt{B^k/W^k}$	Scaled Ratio Score	Ranking
Pesticide	950	290	660	1.20	1.52	1.81	1	1
Water	711	309	402	0.73	1.57	1.52	0.84	2
Health	811	385	426	0.77	1.52	1.45	0.80	3
Fertilizer	417	480	−63	−0.11	1.51	0.93	0.51	4
Food waste	392	604	−212	−0.39	1.67	0.80	0.44	5
Sensory	392	673	−281	−0.51	1.81	0.76	0.42	6
Yields	177	1,109	−932	−1.69	1.38	0.40	0.22	7

B(W) refers to the number of times an item has been chosen as best (worst); BW = Difference Score = B – W; BWi = individual-level difference score for respondent *n*

Table 6 Estimation results of CL and RPL models

	CL	RPL	
Variable	**Coefficients (Std. error)**	**Mean (Std. error)**	**Std. deviation (Std. error)**
Pesticide	1.472*** (0.067)	2.132*** (0.116)	1.129*** (0.099)
Food waste	0.701*** (0.056)	0.914*** (0.084)	1.067*** (0.090)
Sensory	0.641*** (0.057)	0.731*** (0.086)	1.337*** (0.099)
Fertilizer	0.829*** (0.055)	1.090*** (0.079)	0.772*** (0.088)
Water	1.233*** (0.060)	1.725*** (0.098)	1.012*** (0.081)
Health	1.255*** (0.060)	1.773*** (0.099)	1.003*** (0.089)
Yields	–	–	–
Wald-Chi2	666.71***	442.80***	
N Obs	23,100	23,100	
N cases	3,850	3,850	
N individuals	550	550	
LL	−6152.070	−5832.62	
LR		638.89 [0.00]	

CL estimates were obtained using the *maxdiff* command. LR tests against a model with only fixed coefficients or joint significance of standard deviations, and significance implies rejection that the coefficients are fixed

of 1.81 and 1.67, respectively), reflecting more heterogeneous views among consumers concerning these potential implications of CRISPR. Variability is lowest for *Yields* (std = 1.38), indicating more consistent consumer responses to this attribute.

Best–worst estimation results

The estimation results of both the CL and RPL models are presented in Table 6. The attributes entered the model as dummy variables, with *Yields* omitted as the reference category. Both models indicate that all six attributes are statistically significant, confirming the ranking of preferences in which *Pesticide* ranks highest, followed by *Health*, *Water* saving, *Fertilizer*, *Food waste* and, lastly, *Sensory*. Furthermore, the RPL model confirms the presence of preference heterogeneity, as the standard deviations of the random parameters are individually and jointly significant (LR test). The RPL model is

Table 7 Respondents Clusters profiles

Variable	Indicator	Cluster 1 Environmentally driven N = 297 (54%)	Cluster 2 Personal benefits driven N = 253 (46%)	Differences between clusters
Panel a. Benefit preferences: mean (standard deviation)				
Pesticides	–	2.467 (0.717) [1]	1.954 (0.833) [2]	–
Food waste	–	1.051 (0.838) [5]	0.701 (0.728) [6]	–
Sensory	–	− 0.087 (0.629) [6]	1.716 (0.743) [3]	–
Fertilizers	–	1.252 (0.504) [4]	0.959 (0.509) [5]	–
Water	–	1.942 (0.712) [2]	1.627 (0.782) [4]	–
Health	–	1.626 (0.763) [3]	2.069 (0.718) [1]	–
Panel b. Categorical descriptors (% within cluster): Chi-2 statistic [p value]				
Education *	Compulsory (primary, sec)	19.5	22.5	5.374 [0.068]
	High school/equivalent	22.6	29.2	
	University	**57.9**	48.2	
Purchase of organic tomatoes***	Yes	**28.28**	17.00	9.800 [0.002]
Perceived risks about CRISPR				
CRIPR editing may have consequences that are not yet known***	Agreement	**58.25**	44.27	19.702
	Disagreement	3.37	**11.86**	17.440 [0.000]
Panel c. Continuous descriptors (mean): Kruskal–Wallis statistic [p value]				
Perceived risks about CRISPR**	Range 6–30	**21.29**	20.53	4.278 [0.039]
Trust in CRISPR institutions	Range 6–30	**16.68**	**18.01**	8.205 [0.004]
Trust in CRISPR public developers *	Range 1–5	**3.20**	**3.38**	2.951 [0.086]
Trust in CRISPR private developers **	Range 1–5	**2.79**	**3.02**	6.125 [0.013]
Trust in CRISPR regulations**	Range 1–5	2.90	**3.15**	6.984 [0.008]
Trust in CRISPR information (media/social networks)***	Range 2–10	4.82	**5.36**	9.822 [0.002]
Social and environmental concerns about food production sustainability ***	Range 14–70	**55.15**	50.95	23.803 [0.000]

Panel a) Means of each attribute are statistically significantly different ($p < 0.01$) across clusters according to the Kruskal–Wallis statistic (also the t test and ANOVA). Panel b) ***, ** and * stand for significant differences between clusters using a Chi-2 test at 1%, 5% and 10%. Panel c) ***, ** and * stand for significant difference between clusters using the Kruskal–Wallis statistic at 1%, 5% and 10%

therefore used to calculate individual-level taste coefficients,[6] which are subsequently employed to cluster respondents into groups that are internally homogeneous but externally distinct in their preferences, using the k-means method.

[6] Problems of convergence were encountered when aiming at estimating the RPL model with respondents' characteristics (i.e. the Z variables in (1)). For this reason, as an alternative approach to gain more insights about the influence of individuals' characteristics on preferences, we proceeded with the calculation of individual taste parameters and the subsequent cluster analysis.

The CH index was calculated for cluster solutions ranging from 2 to 10, yielding the following values: 179.9, 141.99, 118.68, 105.89, 95.62, 86.13, 85,41, 77,76 and 77.93, respectively. The highest value corresponds to the two-cluster solution, indicating this as the optimal number of segments. Table 7 presents the two consumer clusters along with their characterisation profiles.

The first cluster demonstrates a strong preference for the environmental benefits of CRISPR, particularly the reduction of *Pesticides* use and the improvement of *Water* saving. In contrast, the second cluster, while also valuing *Pesticide* reduction, places relatively greater importance on *Health*-related benefits and shows a noticeably higher preference for potential improvements in *Sensory* quality compared with the first cluster (Panel a, Table 7). Accordingly, the first cluster is labelled "Environmentally driven", while the second is labelled "Personal benefits driven".

The cluster membership is described based on socio-demographic characteristics, conventional and organic food purchasing behaviour, tomato purchasing and consumption habits, knowledge of PBTs (particularly CRISPR), perceptions of CRISPR-related risks, trust in CRISPR-related institutions and food technology neophobia, alongside social and environmental concerns regarding food production. Table 7 (panel b and c) reports only those associations that were found to be statistically significant, determined using the Chi-squared test for categorical variables, and the Kruskal–Wallis test for continuous variables. For completeness, non-significant associations are reported in Appendix IV, Table 13.

Among socio-demographic variables (gender, age, education, income and household composition) only education shows a significant association with cluster membership ($p < 0.10$), with the "Environmentally driven" cluster exhibiting a higher proportion of respondents with university-level education. No significant differences are observed in tomato purchasing habits or consumption frequency between the two clusters. However, a significant association is identified for the purchase of organic tomatoes, with a higher proportion of organic tomatoes consumers in Cluster 1 ($p < 0.01$). No significant differences are found regarding knowledge of plant-breeding technologies, including CRISPR, or with respect to food technology neophobia.

Regarding perceived risks of CRISPR, a significant difference in mean scores is observed ($p < 0.05$), with respondents in the "Environmentally driven" cluster showing a greater level of concern about potential risks associated with CRISPR technology. In terms of trust in CRISPR-related institutions, significant differences are found between the clusters ($p < 0.05$) for trust in developers, regulatory bodies and information sources, with Cluster 2 exhibiting significantly higher levels of trust across all these dimensions. Interestingly, when examining trust in developers more closely, public developers receive significantly higher levels of trust than private developers in both clusters ($p < 0.05$). Finally, social and environmental concerns related to food production and consumption differ significantly between the clusters ($p < 0.01$). Specifically, respondents in the "Environmentally driven" cluster report higher levels of concern about the sustainability of food production and consumption compared with those in the "Personal benefits driven" cluster.

Discussion

This study provides novel evidence on how potential benefits of CRISPR-edited varieties are valued by consumers. Focusing on tomatoes and using data from a representative sample of Spanish consumers, the analysis indicates that consumers value environmental benefits most, particularly the reduction in pesticide use, followed by water saving and health-related benefits. Based on a BWS approach, this finding complements previous research that suggests consumer interest in GE food products can be enhanced when the specific benefits of such technologies are effectively communicated (Kilders and Caputo 2021; Hu et al. 2022; Kilders and Ali 2024) by clarifying which specific benefits are most attractive to consumers. There is evidence that positive perceptions of GE-related benefits foster more favourable behavioural intentions towards the technology (Baum et al. 2023).

Results from both the descriptive analyses and the best–worst discrete choice modelling demonstrate that consumers consider environmental benefits, most notably pesticide reduction, as more important than those in other domains. This suggests a widespread awareness of, and concern about, the environmental impacts of agricultural production. These findings are in line with the results of Götz et al. (2022) who reported that German consumers are significantly more willing to purchase CRISPR-edited tomatoes when the technology is framed as reducing pesticide use, indicating that environmental concerns are central to acceptance. Similarly, a preference for food products grown with substantially reduced pesticide use reflects the findings of Borello et al. (2021) in Italy, where consumers expressed a greater preference and monetary value for fungus-resistant grapes cultivated with lower chemical inputs. Likewise, Edenbrandt (2018) observed a slight preference for cisgenic bread over conventional bread, but only when accompanied by a reduction in pesticides use. Additionally, a growing body of literature similarly finds that benefit-focused information, particularly about environmental improvements, is among the most effective drivers of consumer acceptance of CRISPR and related novel food technologies. For example, Kilders and Caputo (2021) and Caputo et al. (2022, 2025a) showed that consumers respond most positively to sustainability-oriented information, with environmental benefits often outweighing other product features in their valuation. Likewise, Gatica-Arias et al. (2019) reported that potential acceptance of CRISPR technology appears high among Chilean consumers, particularly when environmental benefits are emphasised. Hu et al. (2022) found that visual information emphasising biotechnology's potential to lessen environmental impacts increases WTP for CRISPR-derived products relative to GM alternatives. Structural modelling in Baum et al. (2023) further reinforces this pattern by showing that perceived benefits, especially those tied to environmental improvements, are the dominant predictor of behavioural intentions towards CRISPR foods, while perceived risk play a comparatively minor role. Consistent with this patterns, Deng et al. (2024) showed that providing targeted nutritional or environmental benefit information substantially increased WTP for CRISPR-edited tomatoes and greens. Finally, Kilders and Ali (2024) demonstrated that among multiple benefit domains (health, taste, sustainability), environmental benefits (reduced methane) are systematically ranged as most important in consumers' evaluations. Collectively, these findings align with our results showing that consumers place the greatest weight on environmental benefits, particularly reductions in pesticide use, underscoring that environmental considerations consistently dominate other benefit categories in shaping acceptance of CRISPR-edited foods.

It is evident, however, that not all benefits are equally important or persuasive to consumers, with a clear ranking emerging from the analysis. In this study, water-saving and health-related improvements were also highly valued, whereas attributes such as food waste reduction and sensory improvements were perceived as relatively less important with the increase in production yields being the least important. On an aggregate level, these results diverge from some previous research. For instance, Muringai et al. (2020) reported greater consumer interest in GE and GMO potatoes when health benefits rather than environmental ones were emphasised. Similarly, Marette et al. (2021b) argued that highlighting direct and tangible consumer benefits such as non-browning apples is more persuasive than indirect benefits to the environment or pest resistance (see also De Marchi et al. 2019; Rousselière and Rousselière 2017). Finally, the greater variability observed in the importance attached to sensory quality and food waste reduction suggests more diverse and less consensus-driven among consumers regarding these attributes. Taken together, these findings suggest that the hierarchy of consumer preferences for the potential benefits of GE and CRISPR technologies appears to vary by product type, context and specific application. This underlines the importance of tailoring communication strategies to the characteristics of both the product and the target market in order to maximise consumer acceptance.

The best–worst discrete choice modelling results corroborate the descriptive findings, confirming the ranking of perceived benefits identified earlier. Furthermore, the significant standard deviations associated with the estimated parameters point to substantial heterogeneity in consumer preferences, which is further examined through the identification of two distinct consumer segments. The first segment, termed as "Environmentally driven", places a stronger emphasis on environmental benefits, particularly pesticide reduction and water saving. This aligns with broader concerns around the sustainability of food systems and suggests that for this group, the perceived societal benefits of CRISPR outweigh personal gains. The second cluster labelled "Personal benefits driven", while also valuing pesticide reduction, gives comparatively greater weight to personal benefits, specifically health improvements and sensory attributes, such as taste or texture enhancements. This distinction is consistent with prior literature suggesting that consumers weigh both altruistic (environmental and social) and self-oriented (health and quality) considerations when evaluating novel food technologies (Beghin and Gustafson 2021; Götz et al. 2022; Ortega et al. 2022).

The cluster characterisation offers further insight into the drivers of these preference structures. Educational attainment is higher among the "environmentally driven" segment, indicating that higher education may be linked to stronger environmental concerns. This result reflects the conclusions of Hu et al. (2022) who found education to soften negative attitudes towards biotechnology overall and benefit more CRISPR because it is perceived as milder/less invasive once explained. Furthermore, this cluster includes a higher proportion of organic tomato consumers. The fact that organic consumers prefer traits that improve the environment is consistent with studies that show that organic demand is driven by environmental concerns (Kushwah et al. 2019; Shenoy et al. 2024). However, this does not guarantee they would be willing to purchase GE tomatoes instead of organic ones. While this was not the objective of the paper, we can see that organic consumers have a higher concern regarding risks associated with the unknown consequences of CRISPR-edited food. This interpretation is consistent with previous research demonstrating that consumers generally prefer organic products over GE foods, both at an aggregate level (Shew et al. 2018), and for specific product categories such as bread (Edenbrandt et al., 2018), apples (Marette et al. 2021a), potatoes (Muringai et al. 2020), and grapes (Uddin et al. 2022). Conversely, the "personal benefits-driven" cluster exhibits higher levels of trust in institutions related to CRISPR regulation and development. This group also perceives lower risks associated with CRISPR technology, which likely underpins their more favourable stance towards potential personal benefits such as improved taste or health-related attributes. This result is consistent with the synthesising review of Henderson et al. (2023) showing that trust moderates risk perception, reduces perceived uncertainty, and increases acceptance, while low trust amplifies perceived risks. Similar findings are reported by Cummings and Peters (2022) showing that acceptance of GE foods is strongly associated with trust in institutions (government, NGOs, science). Despite the differences in attribute prioritisation, both clusters share a strong valuation of pesticide reduction. This consistent finding suggests that framing the benefits of CRISPR in terms of reducing pesticide use could be an effective communication strategy to enhance consumer acceptance (Baum et al. 2023; Deng et al. 2024; Götz et al. 2022).

These results contribute to a growing body of literature highlighting the nuanced and multidimensional nature of consumer attitudes towards GE foods. They also underline the importance of segment-specific communication strategies. For environmentally concerned consumers, messages that highlight the contribution of CRISPR to sustainability goals may resonate most strongly. In contrast, for consumers focused on personal gains, emphasising improvements in nutritional quality or sensory experiences may be more persuasive. Finally, while the study provides robust insights, the presence of an educational bias in the sample and the reliance on stated preference methods should be acknowledged as limitations. Future research could complement these findings with behavioural experiments or real-market observations to validate the stated preferences.

Conclusion

This study offers important implications into Spanish consumers' preferences regarding the benefits associated with CRISPR-edited tomatoes.

The identification of two distinct consumer segments underscores the need for tailored communication strategies. A one-size-fits-all approach is unlikely to be effective. Messaging should be customised to emphasise environmental benefits for sustainably conscious consumers and personal benefits for health-focused individuals. The study's findings align with the EC's proposal to regulate NGTs, suggesting that consumer preferences are being accurately reflected in policy discussions. This alignment provides a strong foundation for regulatory support and product development. Trust in institutions involved in the development, regulation, and communication of CRISPR technology is a key determinant of consumer acceptance. Transparent governance, credible information dissemination, and the involvement of trusted actors are essential to build and maintain consumer confidence. Food industry stakeholders can leverage these insights to design product labels and marketing campaigns that highlight the most valued attributes such as pesticide reduction, water savings, and health improvements, based on the target consumer segment. Given current preference distributions, the absence of mandatory GE labelling does not appear to be inconsistent with aggregate consumer preferences. However, this regulatory approach may limit producer's ability to credibly signal specific product attributes and, consequently, to capture potential price premiums associated with consumer segments that value or accept GE-related benefits.

While this research yields several robust insights, it is subject to several limitations that should be acknowledged. First, analysis is based on data from a single European country, limiting the generalisability of the results across Europe. Second, the online data collection resulted in a sample skewed towards higher educational attainment (common in online panels), which may influence responses to complex technologies such as CRISP, although the sample remains broadly representative in terms of gender and age. Third, the information provided to participants emphasised the potential benefits of CRISPR, reflecting current regulatory discourse and much of the existing literature. However, this approach does not fully capture public perceptions, in the presence of uncertainty or potential risks. Relatedly, the introductory framing aligned with European Commission communication but lacked counterbalancing risk information. As no manipulation check was included, framing effects cannot be ruled out. Future research should employ more balanced information treatments and post-exposure perception checks. Fourth, the results may reflect lexicographic or non-compensatory preferences, particularly regarding the avoidance of perceived technological uncertainty. Some respondents may have systematically rejected CRISPR-edited tomatoes irrespective of attribute trade-offs. Future studies should incorporate diagnostic tests to identify such response patterns and assess the robustness of preference estimates. Fifth, the absence of a monetary attribute in the BWS design prevents the estimation of WTP and limits direct comparability price-based choice experiments (e.g. Ballco et al. 2025; Deng et al. 2024). While intentional, future research should combine attribute ranking with cost information to quantify trade-offs more fully. Sixth, consumer knowledge was measured using a single subjective item, restricting insight into the role of objective knowledge. Future studies should consider expanding the analysis of the impact of knowledge on preferences both using scales or multiple items for subjective knowledge and measure objective knowledge. Finally, the hypothetical nature of the BWS method implies stated rather than revealed preferences; future work could further mitigate hypothetical bias through enhanced incentive-compatibility features (Penn and Hu 2018).

These limitations might also serve as a basis for further investigations. Future research might explore whether the findings from Spanish consumers generalize to other cultural and national contexts. Comparative research could reveal how cultural values and institutional trust influence consumer preferences. Complementing stated preference methods with behavioural experiments or market-based studies would enhance the validity of insights. Observing actual consumer behaviour in real-world settings can provide more robust evidence. Investigating how consumer attitudes evolve over time as CRISPR technology becomes more familiar and mainstream would offer valuable insights into long-term acceptance and potential shifts in preference. Given the over-representation of highly educated individuals in the sample, future research should examine how education level and the framing of information affect consumer understanding and acceptance of GE foods. Finally, further research is needed to identify which institutions and communication channels are most effective in building trust and disseminating information about CRISPR technologies. Understanding these mechanisms can inform more effective outreach strategies.

Appendices

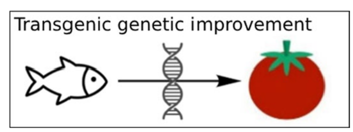
Appendix I

General information

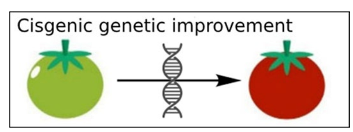
Human beings have certain traits, such as eye colour, hair colour, skin tone, and height, that differentiate us. Similarly, plants have characteristic traits, such as the fibre content of their fruit, water absorption capacity, fruit size and taste, and yield. Historically, traditional plant breeding has relied on varietal crosses. For many years, chemical processes or irradiation have produced improved plant varieties that could have arisen spontaneously. Some of these improvements have resulted in tastier tomatoes, seedless watermelons, and more drought-resistant plants. More recently, new genetic modification or editing techniques have been developed, allowing for the acceleration of the plant improvement process and achieving desired varieties in a shorter time than traditional breeding methods.

There are different types of genetic modification or editing:

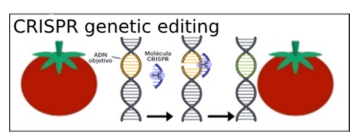
Transgenic genetic improvement involves adding genes from other plants, microorganisms, and/or animals to, for example, the tomato seed being developed. Genetically modified organisms (GMOs) are considered a form of transgenic genetic modification



Cisgenic genetic improvement allows for adding genes only from different varieties of the same plant, implying that the improvement could have occurred spontaneously in nature. With this method, genes from a more disease-resistant type of tomato can be inserted into a less resistant variety. Still, genes from, for example, a fish or an apple cannot be added to the tomato, as is done in transgenic modification



Genetic editing, removes, edits, inserts, or replaces the plant's DNA without introducing external genes. The most commonly used editing method is CRISPR, which is based on a natural defence system that bacteria use against viruses. In this case, the improvement could also have occurred spontaneously in nature



Under the current regulation of the European Union, none of the three techniques are permitted unless approval is sought through a rigorous process. If approved, foods must carry an informative label. However, a proposed new regulation from the European Commission would allow genetic editing (CRISPR) to be used without prior approval, as it is considered a highly safe technique. Only notification of its use would be required. Plant foods derived from new seeds improved through genetic editing (CRISPR) could be sold in the market as if they had been obtained through traditional plant breeding techniques.

Appendix II

See Tables 8, 9, 10, 11.

Table 8 Consumer perceptions about the risks of CRISPR

	The use of gene-editing (CRISPR) in plants may…
1	Have consequences that are not yet known
2	Affect biodiversity by competing with wild varieties
3	Raise ethical questions by intervening in natural processes
4	Generate mistrust in consumers
5	Affect the nutritional composition of products in unforeseen ways
6	Not be accessible to all farmers

Evaluated with a 5-point Likert scale, where 1 = "totally disagree", 2 = "disagree", 3 = "neither agree nor disagree", 4 = "agree", % = "totally agree"

Table 9 Trust in institutions related to CRISPR

1	I trust on scientists (universities, public research institutes) that develop new plants varieties using gene-editing (CRISPR)
2	I trust on companies and private research institutes that develop new plants varieties using gene-editing (CRISPR)
3	I trust regulations on gene-editing (CRISPR) applied to plants
4	I trust on farmers who use the improved seeds developed with gene-editing (CRISPR)
5	I trust on the information that the media (e.g. TV, press etc.) provide on gene-editing (CRISPR) applied to plants
6	I trust on the information that social networks provide on gene-editing (CRISPR) applied to plants

Evaluated with a 5-point Likert scale, where 1 = "totally disagree", 2 = "disagree", 3 = "neither agree nor disagree", 4 = "agree", 5 = "totally agree"

Table 10 Food technology neophobia scale

1	New foods are not healthier than traditional foods
2	The benefits of new food technologies are often grossly overstated
3	There are plenty of tasty foods around, so we do not need to use new food technologies to produce more
4	New food technologies decrease the natural quality of food
5	New food technologies are unlikely to have long-term negative health effects
6	New food technologies may have long-term negative environmental effects
7	It can be risky to switch to new food technologies too quickly
8	Society should not depend heavily on technologies to solve its
food problems	
9	There is no sense trying out high-tech food products because the
ones I eat are already good enough	

Evaluated with a 5-point Likert scale, where 1 = "totally disagree", 2 = "disagree", 3 = "neither agree nor disagree", 4 = "agree", 5 = "totally agree"

Table 11 Social and environmental concerns about the food production sustainability

1	The use of child labour in food production
2	Deforestation of the rainforest
3	Hunger and malnutrition of the world's population
4	The use of pesticides in food production
5	The mistreatment of animals in food production
6	Environmental damage caused by human use of land and water
7	The amount of food wasted
8	The overuse of natural resources for food production
9	Poor working conditions and wages for food producers
10	Non-recyclable packaging
11	The amount of packaging used on food
12	Greenhouse gases caused by food production
13	The amount of energy used in transporting food
14	The amount of energy used in cooking food

Evaluated with a 5-point Likert scale, where 1 = "totally disagree", 2 = "disagree", 3 = "neither agree nor disagree", 4 = "agree", 5 = "totally agree"

Appendix III

See Table 12.

Table 12 Description of items in the Best–Worst experiment. Source: Own elaboration and Annex III of European Commission (2023)

Item (*k*)	Benefits used in the study	Traits as described in Annex III of the proposed regulation European Commission (2023)
1	Reduction of pesticide use	Resistance to diseases and pests (2)
2	Reduction of food waste	Enhance storage, processing and distribution (delaying the ageing of products (5)
3	Improve the sensory characteristics of the products (taste, colour, texture, seedless, etc.)	Improve quality characteristics (6)
4	Stabilising or increasing production yields	Yield, including yield stability and yield under low-input conditions (1) Tolerance/resistance to abiotic stresses, including those created or exacerbated by climate (3) change;
5	Reducing the use of fertilisers	More efficient use of soil nutrients (4)
6	Reduction in water consumption	More efficient use of water (4)
7	Increasing the content of fibre, vitamins, antioxidants, etc., or reducing potentially harmful substances (toxins, allergens, gluten, etc.)	Improve nutritional characteristics (6)

Appendix IV

See Table 13.

Table 13 Respondents Clusters profiles (complementary to Table 7)

Variable	Indicator	Cluster 1 Environmentally driven N = 297 (54%)	Cluster 2 Personal benefits driven N = 253 (46%)	Differences between clusters
Panel b. Categorical descriptors (% within cluster): Chi-2 statistic [p value]				
Gender	Male	45.12	49.41	1.009 [0.315]
	Female	54.88	50.59	
Age	18–34	20.54	19.37	0.590 [0.899]
	35–44	17.51	16.60	
	45–54	22.22	24.90	
	≥ 55	39.73	39.13	
Net household income (€/month)[***],[b]	≤ € 1500 per month	15.15	16.60	1.755 [0.781]
	€ 1501–3000 per month	22.22	24.90	
	€ 3001–5000 per month	21.89	17.79	
	> € 5000 per month	19.53	19.76	
	n.a	21.21	20.95	
Household composition	With children (< 18 years old)	29.29	28.06	0.101 [0.751]
	With retired persons (> 65 years)	20.88	20.55	0.009 [0.926]
	Only adults (18–65 years old)	51.85	53.36	0.125 [0.724]
Tomato purchasing frequency	At least once a week	62.29	64.03	0.178 [0.673]
	All seasons	60.94	66.40	1.757 [0.185]
Tomato consumption	Below average	22.56	19.37	0.836 [0.658]
	Average	38.38	39.92	
	Above average	39.06	40.71	
Knowledge of CRISPR	None	58.59	54.15	5.617 [0.132]
	Low	30.98	30.04	
	Medium	7.74	13.83	
	High	2.69	1.98	
Willingness to consume CRISPR-edited tomatoes	Vey unwilling	11.78	7.91	7.483 [0.112]
	Unwilling	13.13	7.91	
	Not willing not unwilling	41.08	46.64	
	Willing	20.54	24.51	
	Very willing	13.47	13.04	
Perceived risks about CRISPR. CRISPR editing may…				
Affect biodiversity by competing with wild varieties	Agreement	43.43	35.18	4.051 [0.132]
Raise ethical questions by intervening in natural processes	Agreement	42.42	41.50	0.055 [0.973]
Generate mistrust in consumers	Agreement	49.83	43.87	2.387 [0.303]
Affect the nutritional composition of products in unforeseen ways	Agreement	40.07	37.15	0.847 [0.655]
Not be accessible to all farmers	Agreement	48.48	45.45	2.091 [0.352]
Panel c. Continuous descriptors (mean): Kruskal–Wallis statistic [p value]				
Trust in CRISPR use by farmers	Range 1–5	2.96	3.10	2.232 [0.135]
Food technology neophobia	Range 9–45	31.16	30.69	0.471 [0.492]

Panel a) [***], [**] and [*] stand for significant differences between clusters using a Chi-2 test at 1%, 5% and 10%. Panel b) [***], [**] and [*] stand for significant difference between clusters using the Kruskal–Wallis statistic at 1%, 5% and 10%

Abbreviations

CRISPR	Clustered regularly interspaced short palindromic repeats
BWS	Best–worst scaling
EC	European Commission
EU	European Union
GE	Gene editing
GM	Genetically modified
GMO	Genetically modified organisms
NGTs	New genomic techniques
PBT	Plant breeding techniques
WTP	Willingness to pay

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Authos contributions
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Data availability
The authors have full access to the data reported in the manuscript and will provide them upon request.

Declarations

Ethics approval and consent to participate
The article includes a study involving human participants. However, data collection was carried out by a professional research company using their own online consumer panel, in accordance with ISO 20252 (International Organization for Standardization) established ethical standards and participant consent procedures. As the authors had no direct interaction with participants, formal ethics approval and individual consent were not required.

Competing interests
The authors declare no competing interests.

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